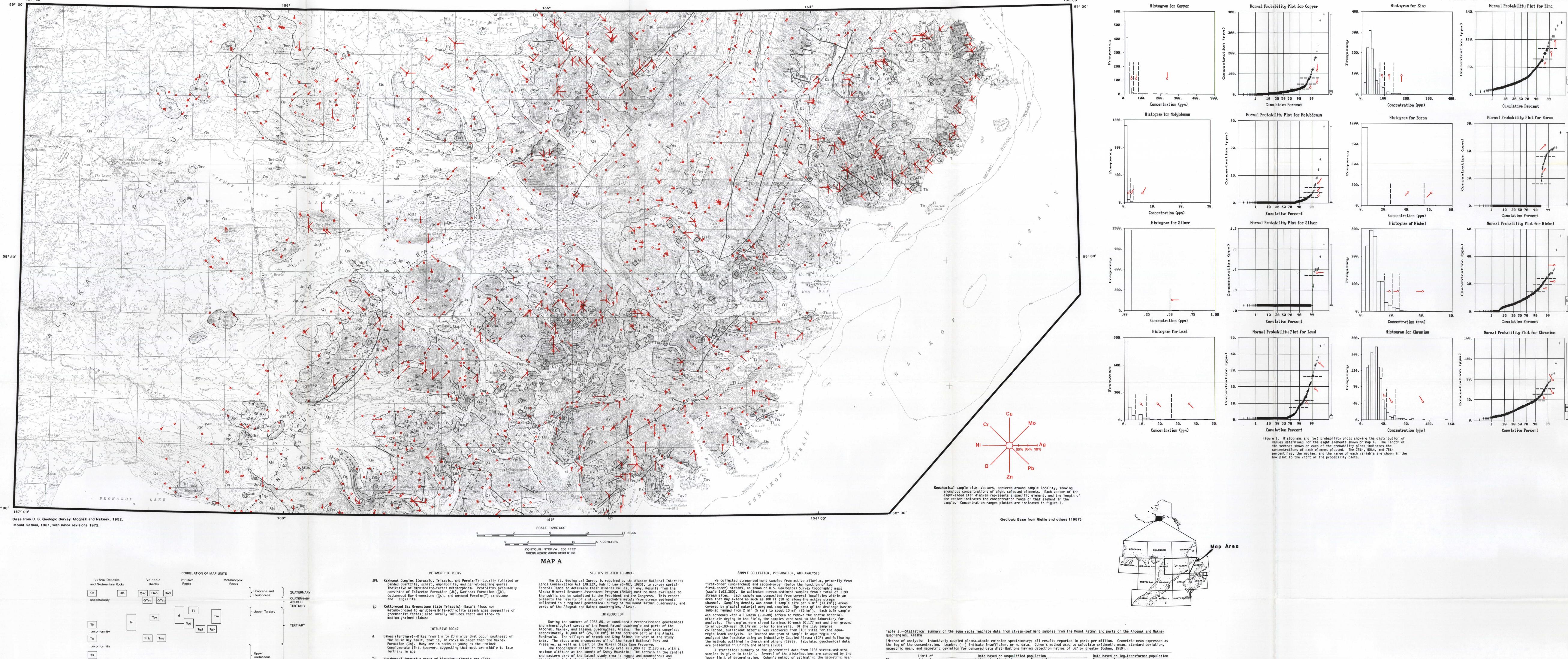
FOLIO OF THE MOUNT KATMAI AREA



				TERTIARY
Th unconformity	Ts Tmb Ti	d Ti d Tgd Tgd Tgd Tg	Tiu Upper Tertiary	- TERTIARY
unconformity				
Kk			Upper Cretaceous	
unconformity			1	
Кр				- CRETACEOUS
			Lower	
Kh			Cretaceous	
local unconform	nity			
Ks			2	}
Jn		Jgd Jqd Jgr Jgb	- Upper Jurassi	С
unconformity		3 144 195 195	-	- JURASSIC
Jt			Lower Jurassi	c
751			Upper Triassic	TRIACCIO
Tik			Trc J Spper massic	
			JPk Lower Jurassi to Upper Pern	JURASSIC, TRIASSIC, AND PERMIAN

Tek Kamishak Formation (Late Triassic)--Slightly to moderately DESCRIPTION OF MAP UNITS recrystallized, non-fossiliferous limestone SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

Qs Surficial deposits (Holocene and Pleistocene)--Unconsolidated to poorly consolidated alluvial, colluvial, glacial, marine, lacustrine, and eolian deposits. Locally includes extensive redeposited pumice and

- ash initially deposited during the 1912 Katmai eruption Qls Landslide deposits (Holocene and Pleistocene) -- Nonsorted, nonstratified
- coarse angular rubble forming lobate masses
- Sedimentary rocks (Tertiary) -- Poorly to moderately well indurated, fluvial sandstone, siltstone, and conglomerate; larger clasts consist of both plutonic and volcanic rocks of local derivation

Age is late Oligocene

Tc Copper Lake Formation (Tertiary) -- Massive, well indurated, polymictic conglomerate, sandstone, and siltstone. Age is early Tertiary

Hemlock Conglomerate (Oligocene) -- Poorly indurated fluvial conglomerate,

pale brown tuffaceous sandstone, siltstone, shale, coal, and tuff.

- Kk Kaguyak Formation (Late Cretaceous) -- Upper part consists of interbedded siltstone and graded greywacke sandstone that represent the upper and middle regimes of a submarine fan. Lower part consists of thinly bedded siltstone and some thin limestone beds and includes abundant ammonites, pelecypods, and limestone concretions
- Kp Pedmar Formation (Early Cretaceous) -- Thick-bedded grey sandstone and minor amounts of siltstone and shale that contain ammonites of Albian
- Kh Herendeen Formation (Early Cretaceous) -- Calcareous sandstone and siltstone, thinly bedded, light- to dark-olive grey Ks Staniukovich Formation (Early Cretaceous) -- Siltstone, shale, and thinly
- bedded, fine-grained, feldspathic and laumontitic brown sandstone Naknek Formation (Late Jurassic) -- Main sedimentary rock-unit of the map area, consisting of sandstone, conglomerate, siltstone, and dark shale. Divided into five members (not mapped here), from oldest to youngest: massive conglomerate and thinly bedded sandstone member; thick-bedded to massive sandstone member; thinly bedded, dark grey

siltstone member with limestone concretions; thinly bedded sandstone

oldest and youngest conglomerate members are dominantly metamorphic,

volcanic, and sedimentary rocks with subordinate plutonic rocks

and siltstone member; massive conglomerate member. Clasts in both the

Jt Talkeetna Formation (Early Jurassic) -- Lava flows, breccias, and lahars locally interbedded with volcaniclastic sandstone, conglomerate, and shale. Includes sills of uncertain ages. Metamorphosed to non-schistose epidote-albite-calcite assemblages suggestive of lower greenschist facies

VOLCANIC DEPOSITS AND ROCKS

Qap Pyroclastic-flow deposits (Holocene) -- Poorly sorted, variably indurated

deposits of ash, vitrophyric blocks, and (or) pumiceous lapilli.

Comprises the 1912 ash flow of Katmai (Novarupta) and the Holocene

Younger central-vent deposits and rocks (Holocene and Pleistocene) -- Lava

Younger deposits and rocks of Aleutian volcanic arc

Qad Domes (Holocene) -- Domes of dacitic or rhyolitic composition

QTac Older central-vent deposits and rocks (Pleistocene and late

block-and-ash flows of Kaguyak caldera

- - Tgb Gabbro and diorite (Tertiary) -- Medium-grained rocks having gabbroic or

 - GEOLOGIC MAP SYMBOLS
 - Fault--Dashed where inferred or approximately located, dotted where
- flows, tuffs, and breccias dominantly of andesitic composition but locally including lava flows of low-silica dacitic composition, airfall deposits of andesitic to rhyolitic composition on Baked Mountain and Broken Mountain, and scoria cones of basaltic composition

Anticlinal axis--Showing direction of sorted, variably indurated deposits of ash, vitrophyric blocks, and/or plunge; dashed where approximately pumiceous lapilli. Primary compositions are uncertain owing to alteration but probably range from andesitic to dacitic

- fossil fumaroles (e.g., bleaching to light red or yellow shades) Tav Older volcanic rocks of Aleutian volcanic arc (late Tertiary) -- Breccias, lava flows, sills, and local pyroclastic and epiclastic tuffs of late Tertiary volcanic field located southeast of the Aleutian Range crest and extending from the Katmai River to Kukak Bay. Dominantly of
- contacts with hypabyssal intrusive rocks of unit Ti Volcanic rocks of Meshik volcanic arc (early Tertiary)--Divided into:
- Tmb Basaltic lava--Plugs, dikes, and flows of basaltic composition that intrude or overlie rocks of unit Tma ma Andesitic and dacitic lava flows and breccia--Unit also includes local domes or tuffs of rhyolitic(?) composition, now altered to quartz and

sericite or kaolinite

- Ti Hypabyssal intrusive rocks of Aleutian volcanic arc (late Tertiary) -- Sill-like or cross-cutting subvolcanic intrusive bodies generally less than 10 sq km in outcrop area, as well as larger
- plutonic bodies such as those beneath Fourpeaked volcano or along the Aleutian Range crest east of Serpent Tongue Glacier. Fine-grained, porphyritic to equigranular rocks that consist dominantly of granodiorite or tonalite and minor quartz diorite
- Tiu Hypabyssal intrusive rocks, undivided (Tertiary) -- Intrusive bodies ranging from small plugs and sills to plutons exposed over as much as 30 sq km. Rocks are fine- to medium-grained, commonly porphyritic, and consist chiefly of quartz diorite or tonalite Tgd Granodiorite (Tertiary)--Medium-grained equigranular to marginally
- porphyritic rocks that are low in modal quartz; unit includes samples that are classified as quartz monzodiorites Tqd Quartz diorite (Tertiary) -- Medium-grained equigranular rocks in which abundance of modal quartz ranges widely, rocks of the unit include tonalite and monzonite
- Jgr Granite (Jurassic) -- Medium-grained equigranular or fine-grained
- Jgd Granodiorite (Jurassic)--Medium-grained equigranular or fine-grained porphyritic rocks. Also includes isolated outcrops of tonalite and
- Jqd Quartz diorite and tonalite (Jurassic) -- Medium-grained equigranular Jgb Diorite and gabbro (Jurassic) -- Dark, diabasic- and gabbroic-textured
- Contact--Dashed where inferred or approximately located

concealed: gueried where uncertain. U=upthrown side, D=downthrown side

dashed where approximately located;

dotted where concealed; queried where

Thrust or reverse fault--Sawteeth on upper plate; bar with number indicates dip of QTap Pyroclastic-flow deposits (Pleistocene and late Tertiary) -- Poorly

located; dotted where concealed; queried where existence uncertain Tertiary) -- Lava flows, breccias, and domes of andesitic and dacitic Area of hornfels composition. Locally moderate to extensive alteration associated with Synclinal axis--Showing direction of plunge;

existence uncertain Measured strike and dip of beds andesitic and dacitic composition. Propylitic alteration is extensive and argillic or potassic alteration is locally intensive, such as near Approximate strike and dip of beds Strike and dip of foliation

⊕ Horizontal bedding

Quaternary volcanic vent Area of alteration

contains youthful stream drainages in previously glaciated valleys. The Valley of Ten Thousand Smokes, formed by infilling of ash flows from the Mount Katmai eruption of 1912 (Fenner, 1920), has been deeply incised and was not sampled. The western part of the Katmai study area is a low tundra plain covered by a deep mantle of glacial, lacustrine, and eolian deposits. There are no outcrops of bedrock exposed. Large glacial lakes preserved in the area were formed behind terminal moraines following the retreat of the glaciers (Keller and Reiser, 1959). Sampling was confined largely to the alpine and foothills terrain in the eastern and central parts of the Katmai study area. This report, one of a series of reports that graphically present selected

geochemical and mineralogical data in map format, presents the geochemical results from inductively coupled plasma analysis of aqua regia leaches of minus-80-mesh stream-sediment samples; MF-2021-A (Church, Bailey, and Riehle, 1989) presents the geochemical results from emission spectrographic analysis of minus-80-mesh stream-sediment samples; MF-2021-C (Church and Arbogast, 1989) presents the geochemical results from emission spectrographic analysis of nonmagnetic heavy-mineral-concentrate samples; and MF-2021-D (Church and Bennett, 1989) presents mineralogical data from binocular microscopic examination of nonmagnetic heavy-mineral-concentrate samples. An interpretive report, which delineates selected areas of mineralization within the study area and interprets the significance of the geochemical and mineralogical

signatures of these anomalous areas, is in preparation. Geologic mapping of the Mount Katmai region includes early reconnaissance work by Keller and Reiser (1959) and preliminary results of the AMRAP study (Riehle and others, 1987). Stratigraphic relations of sedimentary units throughout the entire Alaska Peninsula are consistent with recent revisions (R.L. Detterman, written commun., 1989). The Katmai study area includes part of the Alaska Peninsula magmatic arc. Jurassic volcanic rocks (Jt), which are intruded by coeval or slightly younger Jurassic plutons (Jgr, Jgd, Jqd, and Jgb) as well as by Cretaceous and Tertiary plutons (Tgd, Tqd, and Tgb), comprise the Alaska-Aleutian Ranges batholith that extends from the southern margin of the study area north to the vicinity of Mount Denali (formerly, Mount McKinley) (Reed and Lanphere, 1969; 1973). None of the Cretaceous intrusive rocks found elsewhere in the batholith have been identified despite 38 radiometric age determinations on rocks from the study area (M.A. Lanphere and F.H. Wilson, written commun., 1988). Roof pendants are a heterogeneous assemblage of schist, gneiss, quartzite, greenstone, and amphibolite (JPk), the protoliths of which include Jurassic volcanic rocks (Jt), Triassic basalt flows and limestone (R c and R k), and possibly older sedimentary and (or) volcanic rocks. Extrusive rocks (Tmb, Tma) of middle Tertiary age (F.H. Wilson, written commun., 1987) are part of the Meshik volcanic arc, which extends from the southern Alaska Peninsula north to the Katmai region and perhaps into the Iliamna quadrangle (Wilson, 1985). Tertiary plutons of the Alaska-Aleutian Ranges batholith may, in the Iliamna quadrangle, be the deep-seated equivalents of the Meshik volcanic rocks. Centers of Miocene volcanism (Tav), located immediately seaward of the currently active Quaternary vents (Qap. Qad, and Qac), document the onset of the modern Aleutian arc. Volcanic rocks (QTap, QTac) that are located near and are more deeply eroded than Quaternary volcanic rocks, may be intermediate in age between the older and younger parts of the arc. Shallow intrusions of late Tertiary (Ti) and Tertiary (Tiu) age have locally metamorphosed and (or) hydrothermally altered the older Miocene volcanic rocks east of the range crest as well as the Mesozoic sedimentary rocks west of the range crest. The most extensive rock unit in the region is the Naknek Formation (Jn) a composite of Upper Jurassic shallow marine, littoral, and fluvial conglomerates, sandstones, and siltstones that document the unroofing and erosion of the Jurassic part of the batholith. Younger strata locally preserved in the study area are Cretaceous sandstone, siltstone, and calcareous sandstone (Ks, Kp, Kk, and Kh) and Tertiary conglomerate

sandstone, and siltstone, locally tuffaceous and (or) coal-bearing (Ts, Th,

fault, a high-angle reverse fault 480 km in length (Detterman and Hartsock,

1966; Detterman and others, 1976) that, in the Katmai study area, juxtaposes

the batholith and older rocks on the west against the Naknek Formation on the

east. Other structural features include north- to northeast-trending folds

and northwest-trending, high-angle minor faults, fractures, veins, and dikes;

most or all of such features in the study area are probably late Tertiary in

and Tc). The main structural feature of the study area is the Bruin Bay

The skewness and kurtosis of these censored distributions were

lower limit of determination. Cohen's method of estimating the geometric mean and geometric deviation has been used to estimate these parameters (Cohen, estimated after replacing qualified values with one-half of the lower determination limit of the element if qualified with an L and with one-quarter of the lower determination limit if qualified with an N. The skewness and kurtosis values for both the raw data and the log-transformed data were compared with the table of critical values for the 5 percent confidence limits (Bennett and Franklin, 1954, p. 95) to estimate whether a particular traceelement distribution more closely approximates a log-normal rather than a normal population. All of the data have distributions that are more nearly log-normal than arithmetic-normal as can be readily seen by examination of the probability plots in figures 1 and 2. Selected percentiles of the data are also given in table 1. Data for two groups of elements are shown on maps A and B. Histograms and (or) probability plots of these element suites are shown in figures 1 and The 25th, 50th, and 75th percentiles, the median, and the range of each variable are shown in the box plot (Tukey, 1977) to the right of the probability plots. Anomalous element concentrations are shown, using a star diagram, by vectors for each element that radiate from the sample localities shown as small circles. The vectors are subdivided into three lengths that approximate the 90th, 95th, and 98th percentile distributions of the data. Clusters of anomalous elements indicated by similar vector patterns on the geochemical map may indicate

one or more deposits with large areal exposure. Leaches of the stream sediments serve to accentuate trace-element signatures of both hydromorphic mineral suites and sulfide suites found in exposed mineralization by selective dissolution of these phases (Church and others, 1987). The sulfide and hydromorphic mineral phases are more readily attacked during acid digestion than are the crystallographic sites in silicates because the Gibbs free energy for dissolution of these phases is less than the lattice stabilization energy of the same metal species in a silicate with tetrahedral or octahedral coordination. A comparison of the median values and the histograms for many of the transition metals in this data set, with the data from emission spectrographic results (Church and others, 1989) confirms these generalizations. The resultant leachate data from stream sediments produce positively skewed distributions, the high tails of which reflect the abundance of either hydromorphic or sulphide phases in the sample from a given sample locality. On map A, we have plotted the elements Cu, Mo, Ag, Pb, Zn, B, Ni, and Cr, which is very similar to the grouping used in presenting the data from emission spectrographic results from the stream sediments (Cu, Mo, Ag, Pb, Zn, B, Ni, and Co; Church and others, 1989). On map B, we have plotted the generally less-abundant elements As, W, Analytical results from the study area outline several areas of mineralization. Maps A and B are intended primarily to show the distribution of metals leached from sulfides associated largely with exposed mineralization. A large area of base metal anomalies occurs in the central part of the study area, along its northern border. Here, the anomalies are probably associated with the intrusion of the Tertiary plutons (Tgd, Tqd, Tgb) in the Alaska Range. A second area of widespread geochemical anomalies occurs surrounding Cape Douglas. This area also has widespread arsenic anomalies (map B). A third area of anomalies occurs in the central part of the map, i the vicinity of Mount Katmai and the area to the west. These three areas appear to be underlain by porphyry copper-molybdenum systems. The hydromorphic anomalies (Mn, W, and Mo) and the arsenic anomalies (map B),

ACKNOWLEDGMENTS A number of our colleagues participated in the collection of samples during this study: Karen Duttweiler, Jim Frisken, Wendy Gerstel, Richard Goldfarb, John Gray, Dave Kelley, and Dean Yannacito. Jerry Gaccetta, Michael Jenner, Rick Klebanow, John Unruh, and Dean Yannacito assisted in the sample preparation, and Olga Erlich assisted in the analysis of samples. Bruce Riecke, Berry Roberts, and Ralph Yetka skillfully maneuvered us about in the field via helicopter. This project could not have been completed without the

which occur in the northwest part of the study area underlain by the Tertiary

suggestion is supported by the geochemical data from the heavy mineral suites

(Church and Arbogast, 1989) and the mineralogical studies (Church and Bennett,

volcanic rocks of the Meshik volcanic arc (Tmb, Tma), may indicate the

timely, cooperative efforts of all involved.

presence of concealed porphyry or hydrothermal vein mineralization. This

le ment		Limit of		Data based on unqualified population							Data based on log-transformed population			
		determin- ation	Minimum	Median ²	Arithmetic mean	Standard deviation		ercentiles 95th	98th	Maximum	Geometric mean	Geometric deviation	Skewness	Kurtosis
lq	1.0	20	320	3,200	4,000	2,618	7,500	9,000	10,500	33,000	3,276	1.93	-0.154	0.116
a	1.0	10	370	3,900	4,586	3,719	7,350	8,500	11,000	75,000	3,885	1.79	.244	1.78
e	1.0	150	4,500	29,000	37.882	28,026	76,000	95,000	120,000	340,000	30,740	1.88	.404	.329
1	1.0	30	1,600	9,100	9,569	4,868	15,000	17,000	21,000	71,000	8,520	1.67	360	.031
i	0.958	2.0	7.1	1,000	1,402	1,327	3,000	4,100	5,500	9,800	753	7.23		
)	.947	4.0	15	260	258	142	410	460	545	1,500	197	2.98		
	.041	0.10	27	0.1N					51.5	80				
e	.149	.20	0.20	.2N			0.32	0.47	0.97	10				
r	.959	.20	3.2	24	28	23	55	64.5	76	410	20	3.24		
a	1.0	.03	1.8	34	42	35	87	100	130	290	30	2.47	327	526
a	.972	.90	.90	2.6	2.9	1.4	4.8	5.6	6.6	11	2.6	1.63		
e	.669	.90	.90	2.4	2.3	3.5	6.6	8.2	10	18	1.8	3.13		
	.424	.04	.05	.04N			3.2	4.2	5.5	12				
Ь	.164	1.0	1.4	1.0N			7.6	11	15	34				
In	1.0	1.0	47	320	414	661	635	845	1,300	20,000	329	1.79	.929	5.04
	.959	.75	15	88	104	74	200	250	300	530	76	3.12		
r	.841	1.2	3.6	24	22	17	38	45	57.5	150	17	2.58		
i	.958	1.0	1.1	7.4	8.4	11	15	17	22	330	6.9	2.00		
0	.967	2.0	2.0	8.4	9.8	5.9	17	21	25	43	8.4	1.82		
u	.988	.20	.50	12	17	35	27	36	73.5	910	11	2.58		
lo	.144	.40	.41	.4N			.62	1.2	2.2	30				
b	.157	3.5	3.6	3.5N			8.3	12	19	81				
g	.005	.30	.35	.3N						1.	0			
n	.984	.34	8.0	40			80	97	130	31,000	39	2.22		
d	.010	.40	. 40	.4N					.50	11				
n	.004	2.0	6.0	2.0N						30				
	.027	7.5	9.2	7.5N					9.5	13		4_		
S	.111	5.0	5.0	5.0N			7.0	12	24	190				
b	:003	5.0	14	5.0N						19				
li	.003	16	16	16.0N						33				

REFERENCES CITED Bennett, C.A., and Franklin, N.L., 1954, Statistical analysis in chemistry and the chemical industry: New York, John Wiley and Sons, Inc., 724 p. Church, S.E., and Arbogast, B.F., 1989, Geochemical maps showing the distribution of selected elements determined in nonmagnetic heavy-mineral concentrates from the Mount Katmai and parts of the Afognak and Naknek quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2021-C, scale 1:250,000. Church, S.E., and Bennett, G.J., 1989, Mineralogical maps showing the distribution of selected minerals identified in nonmagnetic heavy-mineral

N, concentration not detected at the limit of determination.

Detection ratio (DR) is the number of uncensored values divided by the total number of samples analyzed.

concentrates from the Mount Katmai and parts of the Afognak and Naknek quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2021-D, scale 1:250,000. Church, S.E., Bailey, E.A., and Riehle, J.R., 1989, Geochemical map showing the distribution of selected elements determined in stream sediments from the Mount Katmai and parts of the Afognak and Naknek quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2021-A, scale 1:250,000. Church, S.E., Mosier, E.L., and Motooka, J.M., 1987, Mineralogical basis for the interpretation of multi-element (ICP-AES), oxalic acid, and aqua regia partial digestions of stream sediments for reconnaissance exploration geochemistry: Journal of Exploration Geochemistry, v.

George, Jr., 1983, Contour maps, statistical summaries, and analytical

area and analyzed using an aqua regia leach/inductively coupled plasma

when samples are singly censored or truncated: Technometrics, v. 1,

data from stream-sediment samples collected from the Glacier Peak study

Church, S.E., Motooka, J.M., Werschky, R.S., Bigelow, R.C., and VanTrump,

method: U.S. Geological Survey Open-File Report 83-366, 116 p.

Cohen, A.C., Jr., 1959, Simplified estimators for the normal distribution

Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p. Detterman, R.L., Hudson, Travis, Plafker, George, Tysdal, R.G., and Hoare, J.M., 1976, Reconnaissance geologic map along the Bruin Bay and Lake Clark faults in the Kenai and Tyonek quadrangles, Alaska: U.S. Geological Survey Open-File Report 76-477, 4 p., scale 1:250,000. Erlich, Olga, Motooka, J.M., VanTrump, George, Jr., and Church, S.E., 1988,

Analytical results and sample locality map for aqua-regia leachates of

stream sediments analyzed by ICP from the Mt. Katmai quadrangle, and

- portions of the Naknek, Afognak, and Iliamna quadrangles, Alaska: U.S. Geological Survey Open-File Report 88-422, 72 p., scale 1:250,000. Fenner, C.N., 1920, The Katmai region, Alaska, and the great eruption of 1912: Journal of Geology, v. 28, p. 569-606. Keller, A.S., and Reiser, H.N., 1959, Geology of the Mount Katmai area, Alaska: U.S. Geological Survey Bulletin 1058-G, p. 261-298. Reed, B.L., and Lanphere, M.A., 1969, Age and chemistry of Mesozoic and
- Tertiary plutonic rocks in south-central Alaska: Geological Society of America Bulletin, v. 80, p. 23-44. 1973, Alaska-Aleutian Range batholith--Geochronology, chemistry, and relation to circum-Pacific plutonism: Geological Society of America Bulletin, v. 84, p. 2583-2610. Riehle, J.R., Detterman, R.L., Yount, M.E., and Miller, J.W., 1987, Preliminary geologic map of the Mt. Katmai quadrangle and portions of the Afognak, and Naknek quadrangles, Alaska: U.S. Geological Survey Open-
- File Report 87-593, scale 1:250,000. Tukey, J.W., 1977, Exploration data analysis: New York, Addison-Wesley, Wilson, F.H., 1985, The Meshik arc--an Eocene to earliest Miocene magmatic arc on the Alaska Peninsula: Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys Professional Report 88,

Manuscript approved for publication, November 2, 1989